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Abstract—**Since 2016, drones have been deployed in various development projects in sub-Saharan Africa, where trials, tests, and studies have been rolled out in countries, including Tanzania, Uganda, Rwanda, Malawi, Ghana, and the Democratic Republic the Congo. The use cases of drones vary, ranging from imagery collection to transportation of vaccines, lab samples, blood products, and other medical supplies. A wide range of stakeholders is involved, including governments, international organizations, educational institutions, as well as industry. Based on a field study conducted in 2019, this article investigates how drones are used for medical supply delivery in Malawi—a country where the community is underserved for healthcare and related infrastructure underdeveloped, while airspace is largely open and regulations generally relaxed. The objective of presenting this case study is to contribute to the evidence regarding the rapid deployment of medical cargo drones across the African continent, and to spark critical reflections over the utility, suitability, and impacts of incorporating drones in the existing health supply chain systems in resource-poor settings. The discussion revolves around two aspects: 1) the emergent "African Drone Rise"—is it ok "as it is Africa"? and 2) the normative role of technology in the aid sector—is it "a solution looking for a problem"? In conclusion, a call for more structured guidance for the systematic examination and evaluation of the medical cargo drone case is raised.**

Index Terms—**Health supply chain system, humanitarian drone, medical cargo drone, medical supply delivery, public interest technology.**

I. Introduction

According to the World Bank, one-third of the world's population lacks regular access to essential medicines [1]. The volume and complexity of global aid programs has spawned extensive and complex health supply chains, many navigating difficult conditions in low- and middle-income countries with poor infrastructure, complex logistics, and lack of resources [2]. Although the humanitarian supply chain represents 60%–80% of humanitarian expenditures, last mile delivery (LMD) logistics is a critical constraint preventing medical supplies from reaching remote areas, causing reported vaccines supplied to parts of the targeted countries to expire before they can be administered [3]. To address the LMD challenge, the use of drones is considered useful to help optimize the health supply chain, due to their technical versatility, operational viability, and economic accessibility [4]. Since 2014, several projects have demonstrated a proof of concept of using drones for medical delivery [5]–[7]. Drone-based healthcare projects have emerged rapidly across the globe with a broad range of applications, especially prominent in sub-Saharan Africa.

Although cargo drones used for development and healthcare purposes are still an emergent approach, there is a wide array of actors involved ranging from tech start-ups to logistics companies, many partnering with universities, NGOs, and international aid organizations [3]. Yet due to the early stage of implementation, to date, little real-world experience or primary data related to technology performance, operations, health impact, cost, or acceptability are available [5]. In addition, the trend of the "African Drone Rise" in recent years, whereby drones and Africa are being construed as solutions to each other's problems, opens up critical questions with respect to the ethical and societal implications of using drones in the aid sector [9], [10]. This article constitutes one element of a research project that examines technological innovation in the aid sector and how it intersects with moral values, norms, and commitments [11], [12]. As part of a set of field studies of different uses of drones by international aid organizations, this case study investigates the use of drones for medical supply delivery in the lake area of Malawi. A detailed narrative account of the case study was presented in [4].

The current paper draws upon the empirical findings of the field study to develop an analysis with the goal of identifying contextualized ethical considerations, and illuminating the wider debate about how ethical technological innovation in the aid sector can be operationalized. This article comprises three parts: 1) a short summary of a case study of a medical drone delivery project, including a detailed presentation of research methods; 2) an in-depth analysis of six categories of challenges that emerged in the context of the case study: a) human and environmental safety; b) cargo safety; c) operational costs; d) infrastructure gaps; e) local capacity; and f) donor dependence; and 3) a discussion around the phenomenon of the African Drone Rise, and the observed mentality of "solutionism," in light of the concerns and critiques raised by scholars and practitioners in the field. In conclusion, I call for a prudent attitude in adopting novel technology in the aid sector and argue that proposals for actionable ethical standards to guide sector-wide innovation practices are needed.

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II. Case Study

A. Drone Delivery Project

In 2017, the Government of Malawi (GoM) established the Humanitarian Drone Testing Corridor, in collaboration with a specialized UN agency, where studies could be implemented on using drones to facilitate LMD and integrating drones in an optimized health supply chain system in low-resource settings [5]. Since then, Malawi has become a popular site for drone testing and pilot projects [4]. In this case study, a donor agency attempted to find a solution to assist the GoM with the LMD challenge by transporting lab samples from the two islands in Lake Malawi—Likoma and Chizumulu—to the mainland, where land-based health logistics established by the Ministry of Health (MoH) are routinely used [4]. An organization, which is referred to as Y in our study, works in the area of public health and international aid, and is involved with selecting, procuring, and delivering medicines for infectious diseases, such as HIV/AIDS, in Africa, Asia, and Latin America [4]. As drones showed potential to provide medical supplies to hard-to-reach areas, Y was eager to test if they could include drones in health logistics, and secured funding for a feasibility study [4]. The study was contracted to a company with the objective to use drones to connect the health centers on the two islands to the mainland as a complementary supply chain solution [4]. Prior to the utilization of drones, the lab samples were transported by a passenger boat which operates twice a week and takes about 6–8 h each way; with the drone, multiple deliveries per day can be performed, taking about just an hour each way, helping reduce the transportation time to a large extent [4]. In July 2019, upon receiving the final approval from the Department of Civil Aviation (DCA), the project entered into full operation [4]. According to the drone pilot interviewed, between July and October 2019, over 200 flights were operated for more than 90 h and delivered about 45 kg of medical commodities over about 30 000-km flight route [4]. During this period, the project undertook routine deliveries, reducing sample turnaround time from 5 to 8 weeks with the boat to less than 4 weeks with the drone [4]. The project was perceived as technically successful as it showcased the state of the art of the technology, and achieved its intended outcome with respect to lab sample transportation during the operation. However, there were also ethical challenges encountered in terms of safety, health impacts, cost-effectiveness, capacity, and sustainability [4]. An analysis of these challenges is provided in Section III.

B. Research Methods

1) Research Design: The case study was carried out in Malawi in October 2019 and February 2020, as part of a larger program investigating "value sensitive humanitarian innovation (VSHI)" and consisting of multiple case studies. The qualitative, interview-based research was conducted within a constructivist paradigm, in which human experience is understood as subjective, local, socially and experientially based, and culturally and historically specific [13]. Study design drew upon case study methodology, and we employed qualitative description as our methodological framework, which aims to gain first-hand knowledge of stakeholders' experiences, and describe their views and perceptions of a particular topic in a language similar to their own [14], [15]. Our rationale of using a qualitative description in this case study is to stay especially close to the data itself, developing a low-inference analysis by directly organizing and synthesizing data without further interpretation [15].

2) Participant Recruitment: We acquired and received the Ethics Review Board approval from the National Commission for Science and Technology of Malawi on 13 November 2019. We then recruited interview participants using two approaches.

1) Guided by an interview plan, we sent email invitations to targeted stakeholder representatives, which were jointly identified by the research team and our local partners. We recruited 12 individual participants, including three development workers (at international and national levels), one drone technician, six government officials (at national ministerial and community levels), and two health workers (at community level). We also convened a focus group of local community members (22 villagers in total). All of these participants were involved in, experienced, or witnessed the drone delivery project.
2) Following a snowball sampling logic, we recruited eight further participants by recommendations of previous participants, to expand the scope of the investigation and gain complementary and contextualized data.

The further recruitment included one elected official, five additional health workers, and two local drone technicians. All of these participants were situated at the community level and were directly involved in the drone project. The final sample of 42 participants thus consisted of a diverse representation of stakeholders engaged in the drone delivery project, consistent with our goal of maximum variation sampling in order to explore the common and unique perspectives on the subject [16].

3) Data Collection: Our main data collection was semi-structured qualitative interviews. All participants provided written informed consent prior to their interview. Other data sources included texts (e.g., publicly available reports), and observations by the author (e.g., how interviewees interacted with each other), who carried out the field study in Malawi as the principal researcher. Two types of interviews were conducted: 1) those that followed an interview guide, which was developed prior to the field study with targeted questions centered around key areas of ethical concerns, was initiated based on expert knowledge and 2) open discussions to explore topics which emerged from the earlier interviews (e.g., the regulatory environment in Malawi, or the particularities of medical drone delivery in the African context). Overall, 12 interviews were conducted between 24 October 2019 and 12 February 2020, including eight individual interviews with a single participant, three panel interviews with 2–5 participants each, and one focus group interview with 22 participants. All interviews were conducted face-to-face and were audio-recorded, ranging from 46 to 169 min in duration (average 87 min). The individual and panel interviews were conducted

TABLE I
CATEGORIES OF ETHICAL CHALLENGE

<table>
<tr><th>Theme</th><th colspan="2">Safety</th><th colspan="2">Operationality</th><th colspan="2">Sustainability</th></tr>
<tr><td>Analytical Focus</td><td>Human & Environmental Safety</td><td>Cargo Safety</td><td>Infrastructure Gap</td><td>Operational Costs</td><td>Local Capacity</td><td>Donor Dependence</td></tr>
<tr><td>Analytical Angle</td><td>• Drone Technology
• Connectivity Solution
• Weather Condition
• Safety Insurance</td><td>• Sample Packaging
• Dangerous Goods
• Patient Data</td><td>• Health Logistic System
• Lab Sample Processing
• Health Facility Capacity</td><td>• Investment
• Beneficiary
• Business Model</td><td>• Locally Based Operation
• Project Management
• Airspace Management</td><td>• Committed Resources
• Structural Roots
• Lack of Knowledge</td></tr>
<tr><td rowspan="4">Ethical Consideration</td><td colspan="6">Is It OK "As It's Africa"?</td></tr>
<tr><td colspan="3">• International Development Challenge: donor-based, high beneficiary expectations, prone to shortcuts due to resource</td><td colspan="3">• Public Acceptability of Innovation: donor confidence, government commitment, community engagement</td></tr>
<tr><td colspan="6">Is It "A Solution Looking for A Problem"?</td></tr>
<tr><td colspan="3">• Technology Experimentation: "do not impose but ask" approach, positive disruption, responsible innovation in the aid sector</td><td colspan="3">• Drone Industry Expansion: business motive, industry lobbying, supply chain bottlenecks, responsible private sector engagement</td></tr>
<tr><td rowspan="6">Lesson Learned</td><td colspan="6">Technical Perspective</td></tr>
<tr><td colspan="6">• Drones: context-specific safety considerations, adaptive risk mitigation measures</td></tr>
<tr><td colspan="6">Impact Perspective</td></tr>
<tr><td colspan="6">• Health: long-term and substantive health outcomes, systematic assessment of cost-effectiveness</td></tr>
<tr><td colspan="6">Benefit Sharing Perspective</td></tr>
<tr><td colspan="6">• Malawi: committed local capacity building, sustainable value creation, proactive stakeholder engagement</td></tr>
</table>

in English; and the focus group interview with the community members was conducted in the local dialect, with translation provided by our local partner.

4) Data Analysis: Data analysis consisted o two steps: 1) generating validated descriptive summaries of the interviews and 2) extrapolating thematic categories for further analysis. For the first step, we developed a written synopsis of each interview, based on the interview recordings and with reference to the available texts and observations, with the support of a research assistant. These synopses were compared with interview notes taken by the author during each interview, leading to a comprehensive descriptive summary of the interviews. The summary was then sent to anonymous reviewers, who were involved in the drone delivery project, to ensure that it was factually accurate. This resulted in a detailed narrative account of the case study, which was presented in [4]. For the second step, core concepts were first developed by themes, and these themes were then clustered in six categories and extrapolated for analysis. Based on this inductive analysis, four aspects of ethical considerations were drawn in light of two key concerns: 1) the emergent African Drone Rise—is it ok "as it is Africa"? and 2) the normative role of technology in the aid sector—is it "a solution looking for a problem"? These findings then led to the conclusion of lessons learned from three aspects, namely, the technical, impact, and benefit-sharing perspectives, summarized in Table I. It is worth noting that these themes represent a rather broad spectrum of challenges, including technical aspects such as safety, and operational aspects such as costs. Some of these aspects may not be ethical issues *per se* such as infrastructure or capacity, or may not exclusively relate to drones, such as patient data, but may nonetheless cause unintended consequences of ethical concerns, and are in that sense considered as having an ethical impact. These categories do not suggest a specific order of criticality and are presented with a horizontal logic for ease of reading.

III. Analysis of Ethical Challenges

While no severe ethical tensions, tradeoffs, or dilemmas are observed in this case study, there are ethical considerations related to safety, operationality, and sustainability among the involved stakeholders. In the following sections, I provide a detailed analysis of how these themes were manifest in the case study, with references to the wider academic literature.

A. *Safety*

1) Human and Environmental Safety: First, the biggest risk for drone operation is the *drone technology* itself. The drone technology has inherent technical limitations—drones are battery powered, and the more powerful the battery, the longer the distance, but also the heavier the payload, and the bigger the drone, hence the more severe safety consequences in the case of a drone crash [11]. Take the drones used in this project for example: they can weigh up to 16 kg, can carry cargo up to 6 kg, and can take off and land in relatively small spaces without requiring infrastructure beyond visual line of sight (BVLOS) [17]. For short distances, or where no pickup is required at the destination site, the drone has the capability to drop packages without landing by hovering and releasing its cargo in a box. For longer distances, or where sample pickup is needed, the drone will need to land for a battery charge. In the case where the drone crashes, there will be a serious risk to human safety when flying over populated areas, or causing environmental damage when flying over the lake. According to the interview participants, at the time of the operation, Malawi did not have official safety regulations, which raised concerns for some stakeholders at the MoH. Although the operations team took precarious safety measures, it was reported that there had been accidents both within and outside of the Drone Corridor, and due to either mechanical or human errors [4]. As the actual drone operations were not executed by the GoM, but by the drone manufacturers or service providers associated with international aid agencies, the safety challenges lie with them to overcome. Compared to manned aircraft, unmanned aircraft regulation is either nonexistent or fairly relaxed currently, making safety issues, including physical and environmental aspects worrisome.

Another factor that causes safety concerns is the *connectivity solution*. According to experts, uninterrupted communication between the drone and the control station is of paramount importance to ensure safety, as the drone needs to be monitored constantly and precisely from the ground station [18]. If the local mobile network is sufficiently established, then the drone can be continuously controlled using mobile data that covers the entire flight route. If such an infrastructure is unavailable, then a customized communication plan needs to be set up, such as a combination of mobile network and satellite. In this project, the drones used in the operation are semi-automatic and can vertically take-off and land, i.e., humans remotely control take-off and landing via mobile network, and then the control is surrendered to the onboard computer during the flight. When connectivity is lost, the drones would remain at its last known position and circle until connectivity would recover, during which time there is an increased likelihood of a crash or a so-called "hard-landing," e.g., affected by wind or other weather conditions. Since the poor communication infrastructure in Malawi caused network interferences to drone navigation, the operations team had to triangulate between the GSM/LTE network with automatic switch to satellite communications, when the former is absent, to make sure that they would not lose the drone mid-air. As the study indicates, this raised concerns among drone pilots and involved community members that, if a drone would lose connectivity when flying over the lake and fall into the water, it would not only be difficult to locate and retrieve it, but cargos, including samples or medicines, would get lost. Although satellite communications are the most reliable and with relatively low costs in initiating the drone operations, technically they are not the most optimal, and economically they lead to higher costs during the operation in the long run [18]. This challenges the proposed scalability of drone delivery in areas where communication infrastructure is already fragile.

A third factor is the *weather conditions*. There are generally strong and lasting headwinds over Lake Malawi [4]. Prior to the operation, the MoH had warned the project team about the unfavorable weather conditions, and urged them to take a cautious approach to verify the capability of the drone to withstand strong winds, as well as to assess any potential environmental risks related to it. During the operation, technical staff at the ground station would check the weather and assess the air speed of the drone, on the basis of which they would calculate the wind speed and decide whether they should abort the flight mid-air. Still, the wind led to one crash, causing the drone to fall directly into the lake. Weather conditions during a flight can impact the success of a drone mission, as inclement weather conditions or significant differences in ambient temperatures may cause drones to lose their functionality [19], [20]. The current state of technology development does not allow the drone to calculate the flight time itself, whereby it decides whether the fight time is more than the maximum allowed flight time and to automatically return. Granted that tracking systems may help locate the area where the drone fell, and with the lay knowledge about the current and waves of the lake, it may be possible to roughly determine where the drone has gone. Granted too that there may be ways of minimizing the potential risk of environmental damage caused by cargo leakage, through secured cargo packaging protocols. These risk mitigation measures, nonetheless, do not reduce the inherent risk of drone accidents caused by adverse weather conditions, or interrupted communications as aforementioned. This raises the question as to whether drones, especially smaller ones, suit the windy environment around Lake Malawi.

A final factor is *safety insurance* which relates to all the above three factors. It is important to note the fundamental difference between manned or commercial aviation flights and unmanned or drone flights with regard to insurance. In the former case, passengers actively accept the risk when they board the flight, while in the latter case, those on the ground do not have the opportunity to accept the risk prior to a drone operation [21]. While the capability of drones in carrying payload or handling wind is critical, it is equally important to establish insurance policies to protect populations in the operation areas. According to the participating interviewees at the MoH, ever since the first drone operator that came to Malawi whose drone "crashed within the shortest possible time and even injured a villager," they have witnessed constant changing of drones from one model to another, none with an insurance policy. They are of the view that as the Malawians never demanded drones, they are largely unaware of potential safety risks related to drones and need protections from the government. According to our interviews, expectations from both the health and the aviation sectors to establish drone insurance, ranging from injury of individuals to damage of leaked medical supplies, is currently high in Malawi. In the absence of an insurance policy in Malawi, the GoM and the respective drone operators opted for signing a mutual agreement to settle the safety insurance aspect of the drone projects in question. Some stakeholders seemed to be inclined to downplay the ethical risks with a reductionist view, focusing solely on the "ethical conduct of business," e.g., no bribery to regulatory authorities, or no dealings with weaponized drone manufacturers. However, the often-overlooked unintended harmful consequences associated with the introduction of new technology may, in fact, be much more detrimental to vulnerable populations and their living environment, no matter how "ethical" the conduct of the business may be.

2) Cargo Safety: With respect to *lab sample packaging*, Malawi takes an approach whereby every blood sample taken is considered infectious until it is tested negative. To ensure cargo safety, the MoH adopts a so-called "three-layer" system. The first layer varies depending on the samples—in the case of a TB sample, the sputum is packaged in bottles with a screw top; in the case of an HIV sample, as it is dried blood samples on absorbing papers, it is packaged in envelopes with seals. These samples are then kept in Ziploc bags, which is the second layer. They are then put in a bigger container made of hard plastic locked with a screw top, which is the third layer. This packaging system is designed to ensure that the person carrying the samples is protected, as is the environment and the bystanders. In this project, the fully packaged samples are placed inside the cargo box, which is made of fiberglass and is attached to the bottom of the drone during the flight [17]. In principle, even if a drone would crash, the cargo box would remain intact, and the risk of sample spillage or leakage should be minimal. However, according to both the technical and health personnel interviewed, as the cargo box itself is not locked and can be opened with a magnet, in the case of a drone crash, the sealed bottles or envelopes may still fall out of the cargo box and be dispersed (although the actual samples may not be revealed unless someone picks them up and opens them). Since the drone pilots do not typically handle the samples, other than keeping track of what is being carried by the drone, and logging how many samples and which types of samples are being loaded into the drone, the drone operators essentially provide a "postal service" using drones instead of ground vehicles. This leaves questions of responsibility for safety risks more complex, if and when there is sample leakage in the case of a drone accident.

The importance of cargo safety related to *dangerous goods* in humanitarian aid and emergency response is strictly regulated by the International Civil Aviation Organization (ICAO) in its 2020 Guidance. In this document, ICAO focuses specifically on the safety risks, responsibilities, and mitigation measures related to potentially dangerous cargos carried by drones [22]. The Guidance also provides technical definitions of "dangerous goods," and recommendations regarding their handling, including detailed guidelines laid out in its four Appendixes. According to the Guidance, examples of dangerous goods include infectious substances such as lab samples for analysis, and toxic substances such as certain medicines or chemical, among others [22]. It also affirms that in the case of biological substances, pathogen data sheets or information about the hazards of infectious substances, including deactivation and waste disposal, should be made available [22]. Given that some of the cargo transported in this project was infectious samples, such as TB sputum, as well as other potentially dangerous chemical supplies, such as lab reagents used to run the sample testing, losing cargo became the second biggest safety concern of the health personnel across the MoH. The ICAO Guidance classifies risks associated with the dangerous goods transported by drones by levels, and recommends risks to be assessed in relation to the consequence of their effects if they are released [22]. It asserts that, in addition to normal flight risks associated with operating routes, obstacles, altitudes, or take-off and landing areas, special efforts must be made when these goods are transported over populated areas, remote areas, or environmentally sensitive land and waters [22]. As governments around the world are currently working on creating and adapting legislation to ensure both safety and development related to the humanitarian use of drones, the regulatory landscape evolves rapidly [3]. Although international development work may not always take place in emergency situations, the safety standards should still apply.

Closely related to sample packaging is the issue of *patient data*. According to the interviewed health personnel involved in sample packaging, the patient data related to the lab samples in this project is personally identifiable, as the samples have both patient name and a unique ID number on them. In addition, this data is also demographically identifiable, as there is a facility code on the sample, as well as a laboratory requisition form which describes the test that needs to be performed on the sample. This means that if the sample is revealed, it is possible to link it with a particular patient who is associated with a particular health facility. Patient confidentiality, therefore, is at risk of being compromised in the case of drone accidents. In the U.S., for instance, medical drone delivery operations must comply with the Health Insurance Portability and Accountability Act (HIPAA), which is a set of regulations established to protect the confidential and private information of patients [20]. According to the Act, HIPAA may be violated if individuals who are not involved in the direct care of patients view patient information on the labels of medical specimens or medications [20]. In this project, the cargo to be transported by the drone is entrusted to the involved health and technical personnel. As the drone pilots receive the sample in packages ready to be loaded into the drone, patient data is handled separately from the drone operation and is collected and processed within the involved health facilities. Concerns, however, arose around potential data leakage as a result of a drone accident. There may be a perception that patient confidentiality risks are not drone specific, as they also apply to traditional health supply chain solutions. Yet, it is noteworthy that there is a heightened risk of unintended harmful consequences caused by the frequency and height, as well as the scope of reach, of drone flights, compared to ground vehicles as the latter depend less on parameters, such as weather and mobile communication. This suggests that downplaying the severity of patient data risks associated with cargo drones is, at the least, an imprudent attitude.

B. *Operationality*

1) Infrastructure Gaps: Despite the media hype and industry excitement, drones are not the silver bullet to the *health logistics system*. For example, in emergency cases where patients on the islands need to be attended, unlike ambulances, drones cannot assist in the transportation of humans. Another example is the case of a drone crash, in which situation the drone-based health supply chain would crash as well. According to the DCA, after a drone crash, the operation must be halted immediately while the technical team returning to the Drone Corridor, undertaking thorough technical checks, demonstrating revised flight strategy, and reapplying for approvals—a lengthy process different from traditional logistic solutions, such as boats or motorbikes. As happened in this project, routine sample delivery got interrupted when the drone crashed during the operation, and the local health facilities had to rearrange logistics, i.e., going back to the passenger boat. These aspects imply that to maintain a stable delivery service, the health facilities on the islands cannot rely solely on the drone, but would need an alternative that is somewhat more reliant, and that they can safely fall back on. As the study indicates, drones were useful to help with sample transportation with an improved health outcome; the problem occurs when the operation got interrupted by, e.g., weather, connectivity, or drone accidents, in which cases the improvement achieved would be setback. The real issue here is not about choosing between drones or ground vehicles, but to ensure reliable and continued health logistic services. What remains, in the long run, is the underlying structural problems of the impoverished public health system in Malawi—had the GoM had more systemic solutions to resolve the LMD challenge in the health sector, drones would have unlikely appeared in their agenda in the first place. The dilemma is that such alternatives are not immediately present to Malawi.

Another challenge relates to *lab sample processing*, which concerns the potential overburdening—as opposed to strengthening—of local health systems. The main factor for sample processing is the turnaround time, which is measured by the total running time (TRT) and classified as T1 (sample collecting), T2 (sample processing), and T3 (test result dissemination). In theory, even though the use of drones does not change T2, the TRT still ends up shorter as a result of the reduced time of T1 and T3. Take the Central Molecular Lab (CML) of Malawi for example: in this project, although the CML received the same number of samples in total, the frequency of delivery has changed with the drone. This, to some degree, helps the lab to reduce the TRT, as there is now a more stable sample inflow compared to the past. On the flip side, however, there are other variables at play, which actually led to a prolonged TRT on some occasions. This is because, since the drone delivery started, both the lab personnel and equipment turned out to be insufficient, although the CML had an increase of staff and a second platform installed in the lab. With the two platforms, the lab personnel had to work days and nights on double shifts to keep up with the increased inflow of samples. Additionally, although the TRT has gone down with a constant sample supply, reality suggests that with the increase of samples, the lab has been significantly hampered by insufficient consumables, e.g., lab reagents for biochemistry tests or full blood counts. This is because Malawi has the so-called "push system" in health consumables supply, and the ongoing supply has not been adapted to the sudden demand for lab consumables and is underdelivered. Furthermore, the increased inflow of samples also hampered the machines themselves due to overworking, which caused some downtime to the lab. As a result, to cope with the drone deliveries, the lab would need more equipment to account for the number of samples coming in, and the same has to apply to the number of staff and consumables. Looking from the big-picture perspective, drones offer a partial solution to a much more complex problem.

The sample processing aspect is closely related to the *health facility capacity* in remote areas of Malawi. Take HIV patients for example: many who need to be treated for HIV are also infected with TB. If a health facility needs to do an HIV viral load test, they also should do a TB culture to understand how the drugs are working to help with the management of the same HIV patient. Unfortunately, donors such as those in this project, have a desired focus on HIV, overlooking other interrelated causes that contribute to the patient's overall conditions. Presently, each district hospital in Malawi has a chemistry lab that can do geneXpert, but only 3–4 labs across the whole country can handle TB culture for a drug resistance case. Yet, it is not immediately feasible for the MoH to drastically improve lab facilities in remote areas, which would allow for local testing of samples. Drones offer the MoH a solution to the LMD challenge they are faced with, and give a sense of relief to the health personnel on the islands. To overcome the infrastructure barriers, the GoM implemented short- and long-term measures. While long-term measures inevitably suggest more budget at the central level, short-term measures give the districts flexibility to use locums to cover the staff shortage. Nevertheless, as Malawi already suffers from a general shortage of health personnel, this measure hardly helps. As such, just like the case of the CML, even if the MoH would be able to install additional lab equipment in remote health facilities, the lack of human resources is still a barrier hard to overcome, let alone the lack of electricity and other material such as the aforementioned lab consumables in those areas. The question, hence, boils down to how to compensate the poor infrastructure with an already-burdened health system.

2) Operational Costs: From the *investment* perspective, the drone operation is an expensive venture as, to date, most drone manufacturers are in start-up modes and are still in the stages of research and development in the technology. The capital cost needed for operation is high, and the maintenance costs, including infrastructure and manpower are even higher, requiring a massive amount of resources to be invested [5], [8], [17]. Traditionally, supply chain management systems account for the costs of device operation and maintenance, as well as transport time, road condition, warehousing, and staff [23]. The cost of adding drones to the supply chain will be determined not only by these measures but also the unique drone-specific considerations [8]. According to an FHI360 study, understanding the conditions under which drones are cost effective is critical, but it is a complex area for investigation [23]. First, the costs include both the cost of the technology and the cost of service provision. These cost models vary substantially depending on the specific system used as well as staff training to operate and maintain them [23]. Second, weather conditions are a big factor in drone operating costs. Knowing the impact of wind, humidity, elevation, precipitation, and temperature on supply chain operations will be critical [23]. Third, in addition to direct costs generated by the drone service, opportunity costs also play a role. On a system level, it is difficult to measure the value of faster turnaround times for lab test results, against the value of having a health provider remain in a facility for a day rather than transporting medical goods [23]. Presently, the cost effectiveness of using drones in the development context is largely unknown [5], [8]. Many donors across the globe have, therefore, kept a vigilant attitude toward investing in medical cargo drones.

From the *beneficiary* perspective, for resource-constrained countries like Malawi, the only way to run drone operations is relying on donor funds. In the case of Malawi, the drone operations do not generate an additional budget for the health sector, and the MoH on its own cannot afford drones. In general, there is the question of how money should be spent in the health sector. For most health personnel interviewed in our study, there is an overwhelming preference for improving the health facility capacity in remote areas, to "flying this small thing around Malawi," as some health workers sarcastically noted. They are of the view that rather than using the precious resources allocated to public health on drone operations, Malawi would be better-off procuring new lab equipment, or training more health workers in the long run. Not only do they perceive the drone operation as wasting resources but also the result of improper agenda setting at the central level. For the MoH, however, although drone operations cost a larger sum of funds, if it indeed proves to be cost effective in bringing better health outcomes, they are willing to seek donor funds and justify costs. In reality, due to the above-mentioned lack of knowledge on the actual costs of drone operations, most donors are currently still interested in testing a proof of concept by investing in a pilot study to explore the operational feasibility. These projects tend to be short term from a few days to a few weeks, of experimental nature, with predefined objective and methodology, and managed by international operations teams [4]. Although the future of medical cargo drones is promising, the immediate challenge comes down to the cost of running the service on the ground in resource-constrained environments. Hence, the beneficiary governments need to carefully review the long-term costs to assess if drones indeed make sense to their particular contexts.

The challenge on the system level also relates to the so-called *business model* of medical cargo drones across Africa. As the current practices suggest, there are different donors and healthcare providers independently conducting drone operations in different countries [5], [8]. From a knowledge building perspective, some of these projects can be complementary to each other, in terms of types of drones used (parachuting or vertically take-off/landing), modes of delivery chosen (one-way dropping or bidirectional pick-up/dropping), flight routes defined (long- or short-distance), etc. [5]. Still, working in silos may potentially create competition over attention, resource, agenda setting, and even the airspace. Countries like Malawi, where health systems are already fragile, need a healthy and sustainable environment to incubate innovation. In addition, drone development, impact evaluation, and final implementation require longer-term investment with funds that go beyond pilot projects [5], [17]. This leaves a large investment space for the private sector, where venture capital funds are available to enable the technical robustness needed. However, it is worth noting that cost-effectiveness analysis may not be the top priority for such investors, as they may not be seeking cost-effective interventions; but rather, are keener on finding out how to operate drones on the ground in the development space, and how to integrate this technology into an existing supply chain while the operational costs continuing to decrease as the technology further matures [24]. Ultimately, it is up to the national governments to assess their needs, conduct cost-effectiveness analysis, and gauge in between various tradeoffs that are particular to their own contexts.

C. Sustainability

1) Local Capacity: The key for the GoM to integrate drones in the existing supply chain system, in the long run, is the issue of *locally based operation*. To keep operations local, human resources, including trained remote pilots, drone operators, and technical project managers, are essential. Take BVLOS for example: there is an increased risk in these applications as human control is minimum, and the drones rely primarily on computer systems [19], [20]. Specialized pilots with technical skills, including both knowledge and experience, such as uploading flight plans in the case of an inconsistent mobile network, are needed. These pilots are costly, and are typically unwilling to stay for a long period of time, due to their unfamiliarity with the challenging operational environments. Although Malawi has some capacity to fly drones, the GoM has not yet been able to systematically develop such capacity. In the context of this project, there was an agreement between the GoM and the operators that, once the testing proves to be successful, they will have Malawian pilots trained locally in order to ensure the sustainability of the project. This, unfortunately, had not yet taken place, as the project was still in the early phase at the time of our study. Battery charging and cargo loading offer two more examples. Health personnel may have a role in loading/unloading a drone, confirming schedules, securing a landing or dropping site, documenting deliveries, and even launching the drone—each would require training and time [8]. If drone operations were to be scaled in Malawi, existing health personnel need to be retrained with these responsibilities. In reality, however, the MoH saw that the donors came in with their own operations teams, and few health personnel have been trained so far. It remains unclear whether, and if so when, the GoM will be able to build the local capacity to manage the technical processes independently—how many batteries they will need to manage, who will handle the technical problems associated with loading cargos in drones, and how they will organize the maintenance of the drones in case of mechanical errors or crashes, etc.

The drone operation is a combination of the technicalities of the drone and *project management* knowledge, including especially the implementation of the drone operation in resource-constrained environments. The management of drone operations involves complex planning, including landscape research, identifying the country, designing the activity, successful procurement, contracting, stakeholder management, and getting approvals for flights. Additional aspects include hiring local staff, getting buy-in from local communities, sensitizing local communities, creating communication processes with medical staff for deliveries and pick up, as well as overall management of the budget and subcontractors. Similarly, testing, licensing, and certification of drones need to be done and need to be streamlined and made local and affordable. In countries where technical resources and human capacity are limited, such as in Malawi, an international drone service provider may present a valuable option during an initial phase. Ultimately, local capacity needs to be strengthened as drone service providers can be costly, and might not always be able to deliver the optimal solution for every setting [25]. For sustainable in-country drone operation and its maintenance in the long run, local capacity building is a critical factor and should be demanded by governments, facilitated by implementers, and supported by donors [26]. As with any innovative health intervention, the sustainability of drone-supported healthcare systems will further necessitate strong capacity building, an efficient impact monitoring and evaluation cycle, as well as in-country commitment, including investment in drone regulations, project design, and long-term ownership [5]. This involves multistakeholder consultation, and potentially the development of new regulations which, again, implies costs as well as the need for local capacity.

With respect to *airspace management*, the touchy issue of drone regulation is at play. Air space is highly regulated by civil and international aviation authorities, especially with respect to manned aircraft where air space regulation is currently much more established than in the unmanned space. Although drones fly at much lower altitudes than most manned aircraft, all aircraft pass through low-altitude space, thereby requiring coordination. For drones, technical issues relate to battery life, payload capacity, and the ability to detect and avoid any problems from the control station. Safety and security issues include the drone's ability to avoid near misses, collisions, and accidents as well as hijacking and espionage [19], [20]. Administrative issues related to drone operator training and licensing and the service provider's legal compliance, fiscal health and compliance, and service costs [19], [20]. To achieve continued growth in drone applications, drones must meet or exceed the requirements specified in each of these regulatory areas [19]. Regulators should therefore think beyond borders and in the longer-term about the need for integrating drones in the existing logistics systems in general [5], [8]. Like many countries in the world, Malawi did not have drone-specific regulations at the onset. Through a lengthy process of learning, Malawi started its own regulation development in 2016, and now has drone pilots who are not only certified to fly drones, but are involved in drafting national drone regulations. However, as the main focus at the DCA is manned aircrafts, drones create an additional job for the staff, requiring dedicated manpower to supervise. In civil aviation, there is undefined global authority—ICAO acts as a facilitator and coordinator, while governments expect ICAO to take a lead with standards, following what they have done with manned aircrafts. However, due to a lack of prior experience with drones, ICAO is also learning from the industry and seeking help with setting up the appropriate procedures globally. In the long run, airspace governance for drones will need to address the interlinked issues of safety, privacy, accountability, and sovereignty. To this end, ICAO and governments will have to anticipate future uses of the drone technology, including humanitarian, development, and healthcare applications, taking into consideration the interests of a broad array of stakeholders [1].

2) Donor Dependence: For countries like Malawi, governments need *committed resources*, both human and financial, to improve infrastructure and provide services to their citizens. Traditionally, if the GoM identifies needs and gaps, they will approach donors and solicit funds, donors will then evaluate their "aid-worthiness" and allocate funds accordingly. This leaves the GoM in a conundrum: for donor-funded projects, the donors direct what they want to do with their funds, decide which issue or location to tackle, and whether to commit further funds or withdraw—all of which are beyond the reach of the GoM. Even when donors partner with the MoH, such as in this project, the MoH is not in the position to negotiate possibilities regarding how to allocate resources. If the donor chooses HIV, then malaria is out of the scope, even if there may be bigger needs [27]. And if the donor funds run out, then the project ends, even if the health outcome would be setback and those that are involved would be negatively impacted. In the case of this project, unlike mainland Malawi where land-based health supply chains are available, interruption of donor funds would be especially harsh for the villagers on the islands, and the seemingly improved patient care may well become a once-in-a-life-time experience. Take cargo drones for example: the payload of a drone must make not only technical but also economic sense; otherwise, flying a drone would not be dissimilar to flying a manned aircraft. As the drone technology has evolved, challenges have arisen as regards aligning technology partners with stakeholder needs. How to ensure that drone applications will address relevant problems by teams who understand both the technicalities of the technology and the local contexts remains a challenge [8].

The rise of medical cargo drones in Malawi has its *structural roots* because the existing problems are multifaceted—some are location targeted, others are issue targeted; consequently, some districts have a lot of donor supports, while others are suffering. Malaria, for instance, is an issue across sub-Saharan Africa; HIV has been prevalent since the 1980s till today and is bound to stay. According to the interview participants, the health sector of Malawi receives a lot of innovation initiatives from donors, and as long as they help improve the health system and potentially save lives, the MoH would support them. At the same time, there has been an outcry among the District Health Officers that, sometimes, the donors "want to do what they want and not what we want." The ideal way of addressing the health challenges of Malawi should be district mapping according to respective health needs, driven by the MoH. In reality, however, when donors come to Malawi, they may come with their own ideas regardless of the particular conditions and capacity at the local level. Since it is additional resources which will assist in one way or another, the GoM seizes the funding opportunity. And when those initiatives are to be implemented, the decisions may have already been made at, and passed through, the central level. Districts may not be informed prior, or consulted about which donors are needed, and which areas are to be supported. Given its poor infrastructure and a lack of local capacity, to what extent drones can really offer a solution to tackle these intersectional and complex systemic problems of Malawi remains to be seen.

One reason leading to donor hesitance in committing to long-term investment in medical cargo drones is the *lack of knowledge* about the outcomes of various pilot projects. The health supply chain challenges of Malawi are cross-cutting issues. Donors across the globe look at what health impacts drones could really make, and whether local health capacity may actually be strengthened by introducing drones, within the time frame of operations [24]. According to the interviewed MoH personnel, since not even one project has made significant impact in Malawi so far, perceptions of donors regarding what drones are capable of, and whether drone operations are indeed "aid-worthy," have been negatively affected. In terms of the scalability of drones in countries like Malawi, it will be dependent on a few factors: 1) the availability of local skills, which is essential because the current experience shows that maintaining the international staff in Malawi is neither feasible nor cost effective; 2) the evidence of value creation of adding drones to the existing health supply chain systems, which requires a solid monitoring and evaluation framework that could track progress; and 3) the maturity and cost of the technology itself, as currently there are important drone parts that cannot be manufactured locally and have to be imported, the purchasing, maintaining, and repairing of the drone can thus be burdensome. And finally, the question about the business sense in manufacturing, which depends on the use case and whether there is a business opportunity. The global drone community has a culture of optimism—people see a few tests and assume that everything is figured out; but there is actually still a lot more to understand. Until these questions are answered, unless there is some donor who firmly believes in the technology and decides to invest in massive scalability regardless, the overoptimistic scenario where the operation costs will get lower and local skilled labor becomes available for running drones would be far-fetched.

IV. Discussion

It is often perceived that the biggest *international development challenge* is the aid sector itself, as everything is based on donors; yet the interconnectedness among, and the complexity of, human development issues are not always fully recognized by donors working in the development space [27]. Beneficiaries would expect that if donors are providing a service, they would continue providing it without interruptions. Such a perception commonly exists in projects involving donor funds, which can be decreased or discontinued. There is, hence, the risk that expectation and dependence are created, while services fail to deliver due to operational reasons and donor preferences and their funding behavior [27]. Reality requires development actors creating a system that benefits populations in need, while keeping in mind that projects are determined by funding and may come to an end. The fact that donor funds may exhaust, and projects may terminate—sometimes after people have got used to the benefits—may not be an ethical issue in itself, but it is a limitation that the development sector faces historically [27], [28]. In the case of medical cargo drones, the discussions have been that if the drones are used to bring medical supplies to populations in need, then such innovation helps generate greater public good. Traditional means of transportation do not involve innovation, but they can also create dependence, can cause potential risks, and can fail to deliver. Therefore, giving a chance to demonstrate the potentials of drones as an alternative to the existing health logistics does add value. This may be true to some degree; the danger, however, is that in the development sector, people often look for shortcuts and drones provide such an option [9]. The least-developed countries across the world have the same challenge of lack of development of infrastructure. In Africa, the biggest challenge tends to be roads, which fuels the narrative that "Africa needs more drones than roads" [9]. As this case study illustrates, Malawi has its unique environments that other countries do not have, some of which are in favor of using drones (e.g., government support and health need), others are disadvantageous (e.g., mobile connectivity and weather conditions). This raises the question as to whether drones indeed offer an appropriate solution for countries like Malawi in the first place, which currently has no existing guidance for decision makers to refer to when developing innovation strategies.

With respect to *public acceptability of innovation*, there are three levels to it: 1) the donors—how much they truly believe in the technology, and what tradeoffs they perceive; 2) the local government—how risk averse they are, and how they could benefit based on rational calculations; and 3) the community—how much they understand new technology, and how they associate it with local beliefs, norms and values. For donors, when a new technology is introduced, they assess whether it offers solutions to existing problems, how best to utilize it as a tool to benefit public health or development, what makes sense, and what is a waste of the resources. For local governments, although there are issues around resource availability and local capacity, innovation is generally welcomed, as long as it makes positive change and visible impacts. For communities, they need to be actively engaged in the process, starting from an accurate understanding about the potential risks of the technology to be introduced. In terms of drones, as there is not much experience anywhere in the world, the business model for drones is not yet clear [5], [8]. Is it better to outsource drone services to the private sector, or to build in-house capacity within implementing organizations? What sort of monitoring and evaluation systems are needed? These questions call for practical guidance to facilitate decision making. Although the indicators of success are unlikely to change with the introduction of drones, measuring how performance changes around the introduction of this new technology in particular settings will be key to understand its value [8]. As technology evolves, the general public's understanding of how things work evolves, and the government's tolerance and willingness to give approvals evolves as well. Just as with anything else, the more experience and exposure people have to new technology, the more familiarity with it they develop, and the better equipped they are to understand the nuances, the suggested benefits, as well as the potential risks—which may or may not cause actual problems, but the awareness of them is crucial. Although drone delivery is likely to advance quickly over the next few years, it remains unclear whether, outside of limited delivery of small payload of medical supplies, there is a clear case for drones to be deployed specifically to assist international aid [10].

Regarding the *technology experimentation* aspect, a lot of innovation initiatives have been proposed to Malawi in the name of study or testing. Some were rejected by the GoM, others were pushed on and got implemented in different districts. In our study, interviewees from the health sector raised questions around why "testing things out on Malawians before giving it to others," why accepting it when "they make their need our need," and why not insisting that "we want something that we want." While acknowledging the importance of foreign aid, they were disappointed about "feeling powerless because we are poor," and wished to have the "do not impose but ask" approach. For decades, Malawi has been a relatively "free" space—not just for drones but for development projects in general [27], [28]. Countries like Malawi are receptive to aid because there are needs and gaps everywhere, rendering them particularly vulnerable to "solutions," including those that are looking for a problem. The involvement of the tech sector in the development world may not necessarily be negative, but the emphasis should be on a careful and holistic approach, such that beneficiary countries can be truly empowered by the proposed innovation, and can actually manage its applications in their own capacity. Government institutions play a critical role in facilitating project approval, negotiating with regulatory bodies and ministries, and coordinating a country approach among all health stakeholders even in cases where domestic funding cannot be provided [5]. After all, drones can be disruptive in both good and bad ways. In a positive sense, their introduction can potentially break down existing barriers between departments who previously worked in silos, and help integrate the health supply chain systems through coordinated efforts. The tension lies between insider and outsider tactics in the use of drones—policymakers and innovators alike should engage in a broad and inclusive discussion about how principles might be best balanced, as public accountability is humanitarianism's corner stone [8]. Ultimately, aid provision is not about drones, but about being able to serve populations in need. Challenges arise as to how best to engage the private sector, which lacks well-thought-through guidance in its current state of development.

The *drone industry expansion* from the civilian space to the humanitarian and development world, where drones create a significant new market while potentially adding value such as delivering medicines, has been aggressive in recent years [10], [29]. As the industry eyes civilian applications for its products, it is likely that governments, as well as aid agencies, will be subject to extensive lobbying efforts, including both the procurement of the so-called "humanitarian drones" and the push for the inclusion of it as part of international engagements [30]. Humanitarian and development organizations must, therefore, carefully consider the practical, ethical, and legal implications of these developments. In terms of tradeoffs, would the cost of the drones divert resources from a better use? Do drones represent a risk to affected populations, which is at least as great as the risk to be eliminated by the health sector? Will drones remove work from, or create additional work to, people who are currently in the workforce? How would drones, as well as the aid organizations behind them, be perceived by locals who may have hardly or may even have negative experiences with, flying object? How would they experience routine flights over their village or their houses and heads? Would it be something culturally acceptable or accepted with hostility? How will the drone industry contribute to building the interdisciplinary capacity as many seemingly unrelated sectors could actually be affected? These questions, again, call for actionable guidance, which needs to be evaluated against a comprehensive needs assessment regarding existing resources and bottlenecks in the health supply chain system and associated issue areas. The complexity of health logistics in low-resource settings requires dedicated stakeholder engagement, and the drone industry is an integral part of it. This is not only the responsibility of a government but also the industry should make strides in the analysis of demand and the network of the issues of concerns as well—before proposing and initiating a drone project.

V. Conclusion

While the defense and intelligence sectors were the early adopters of drones, the development sector, along with the commercial sector, has begun to leverage the technology to reach the hard-to-reach. To counteract the negative perception of drones and avoid the more stringent regulations in the Global North, Africa has become a hotspot for the drone industry to develop technology and to obtain legitimacy [9], [31]. Most development programs utilizing drones in the health sector aim to supplement the traditional health logistics in geographically challenging areas and low-resource environments, through collaboration with governments, the private sector, and international organizations [30]. As the drone technology advances, it is likely that the use of drones for logistics in global health will become increasingly viable as—when deployed responsibly and effectively—the drone technology can potentially add value to enhance health supply chain performance, improve access to health services, and create greater public health outcomes. As the aid sector embraces innovation, it opens up a unique space for technology, which may be deployed with a "solutionist" mentality by aid organizations [4], [11], [12]. Whether these innovation proposals can substantively solve the actual problems of the countries they intend to serve, in a sustainable manner and in the long run, remains to be further examined and elucidated. As proposed in this article, ultimately, the key lies with ensuring rigorous reflections about the ethical challenges technological innovation may invoke, developing responsive methodologies to assess its potential for harms relative to potential for benefits, and establishing actionable ethical guidance to identify, address, and tackle such challenges. Following these insights, future work should strive to establish a humanitarian innovation framework that is value-sensitive and context specific, and geared toward determining practical courses of action to address these concerns.

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